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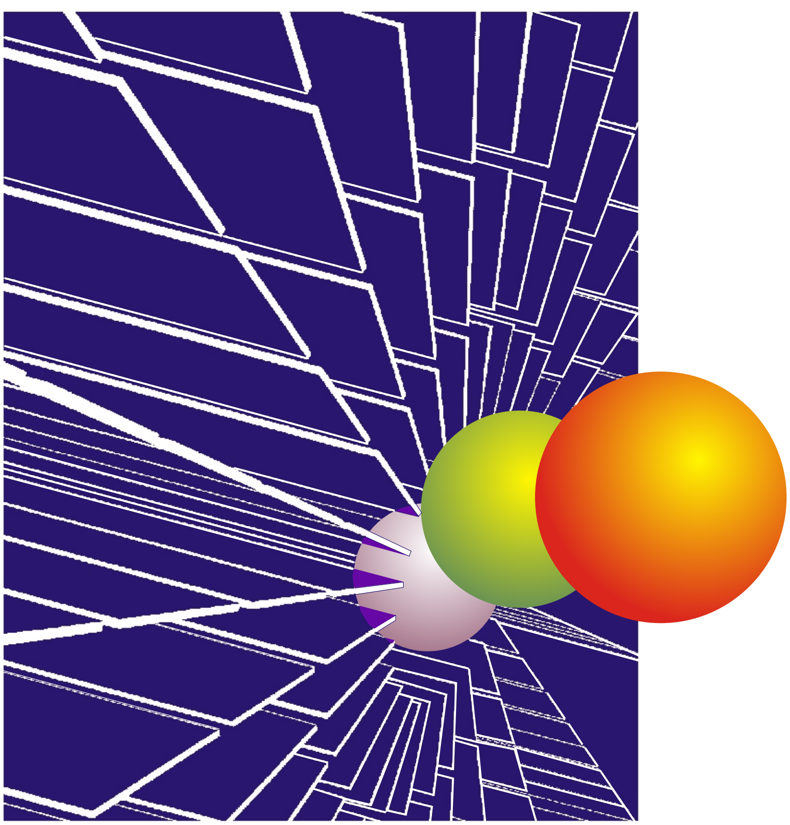

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The investigation was conducted by the University of Missouri-Rolla in cooperation with the Missouri Department of Transportation

16. Abstract

Geophysical surveys were conducted for the Missouri Department of Transportation (MoDOT) by the Department of Geology and Geophysics at the University of Missouri-Rolla. This report contains the results of several projects that utilized nondestructive, geophysical methods. The purpose of the research is to determine successful applications of geophysics to geotechnical work and gauge the effectiveness of different methods. These methods include ground penetrating radar, shallow seismic reflection, electromagnetic induction (EM), and electrical resistivity. Geophysics successfully assessed roadway and subsurface conditions with nondestructive, continuous profiles.

Case studies in this report address karst related voids and sinkholes, underground storage tanks, bridge scour, and abandoned underground mines. A protocol for evaluating the utility of ten commonly employed geophysical methods is provided in this report. This protocol serves as an aid to the highway engineer in the selection of appropriate methods for the target and site.

The GPR proved to be of useful utility in profiling the shallow subsurface soil structure and the reflection seismic survey established the bedrock structure below. Electromagnetic induction proved useful for mapping underground tanks and utilities, while resistivity was used for mapping bedrock and searching for air filled voids such as caves.

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Application of Innovative Non-Destructive Methods to Geotechnical and Environmental Investigation

FINAL REPORT

RDT 03-008

PREPARED BY

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EXECUTIVE SUMMARY

Several geophysical surveys were conducted for the Missouri Department of Transportation (MoDOT) by the Department of Geology and Geophysics, University of Missouri-Rolla (UMR). The objectives were two-fold. First, MoDOT wanted to evaluate the utility of these non-destructive/non-invasive geophysical methods as applied to geotechnical and environmental site-investigations. Second, MoDOT engineers wanted additional independent and/or confirmational subsurface information at the geotechnical sites studied.

Four geophysical methods were employed during the course of these surveys: ground penetrating radar (GPR), high-resolution shallow reflection seismic, electromagnetic induction (EM), and electrical resistivity. Subsurface applications included identifying and locating underground storage tanks and buried utilities, quantifying fluvial scour, profiling bedrock structure, locating in-filled sinkholes and sub-pavement voids of karstic origin, the determination of the thickness and volume of surficial chat (milled waste rock), and locating abandoned mine access and ventilation shafts. The geophysical techniques employed proved capable of expediting the identification, location and mitigation of threatening geological features. A protocol for selecting appropriate non-destructive geophysical methods for specific objectives is included in this report.

The surveys explored the shallow subsurface without damaging pavement and disturbing the subgrade. Time wise, they allowed MoDOT to quickly map the subsurface. Underground objects were located and outlined on the surface to prevent damage by future drilling or excavating equipment. In contrast to geophysics, typical intrusive procedures such as drilling or backhoe excavation are time consuming and costly when used for subsurface exploration. In the case of underground tanks and buried utilities, possible damage could occur where these features are unknown. Geophysical methods were found to be capable of delineating these underground anomalies and the data was used as guidance for the drilling or excavating program. An efficient drilling plan reduces risk, liability, and cost while obtaining pertinent subsurface information. This is especially important on highways, where the goal is to minimize disruption of traffic and damage to pavement.

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INTRODUCTION

Several geophysical surveys were conducted for the Missouri Department of Transportation (MoDOT) by the Department of Geology and Geophysics, University of Missouri-Rolla (UMR). The objectives were two-fold. First, MoDOT wanted to evaluate the utility of these non-destructive/non-invasive geophysical methods as applied to geotechnical and environmental site-investigations. Second, MoDOT engineers wanted additional independent and/or confirmational subsurface information at the geotechnical sites studied. Currently, MoDOT contracts geophysical work as a reactionary measure when subsurface problems express themselves at the surface or where known geotechnical problems or uncertainties exist. MoDOT relies on its Geotechnical Section to discover potential subsurface problems during preliminary drilling of roadways and structures and does not contract geophysics on a routine basis.

Four geophysical methods were employed during the course of these surveys: ground penetrating radar (GPR), high-resolution shallow reflection seismic, electromagnetic induction (EM), and electrical resistivity. Subsurface applications included identifying and locating underground storage tanks and buried utilities, quantifying fluvial scour, profiling bedrock structure, locating in-filled sinkholes and sub-pavement voids of karstic origin, the determination of the thickness and volume of surficial chat (milled waste rock), and locating abandoned mine access and ventilation shafts.

In contrast to geophysics, typical intrusive procedures such as drilling or backhoe excavation are time consuming and costly when used for subsurface exploration. In the case of underground tanks and buried utilities, possible damage could occur where these features are unknown. Geophysical methods are capable of delineating these underground anomalies and the data can be used as guidance for the drilling or excavating program. An efficient drilling plan reduces risk, liability, and cost, while obtaining pertinent subsurface information. This is especially important on highways, where the goal is to minimize disruption of traffic and damage to pavement. Non-destructive testing methods such as geophysics meet these criteria.

RESULTS AND DISCUSSION

The geophysical techniques employed in this study proved capable of expediting the identification, location and mitigation of threatening manmade and geological features. A protocol for selecting appropriate non-destructive geophysical methods for specific objectives has been prepared and is included as Appendix A, “A Protocol for Selecting Appropriate Geophysical Surveying Tools Based on Engineering Objectives and Site Characteristics.”

The ground penetrating radar (GPR) tool was used (in mono-static mode) to image shallow soil and/or shallow bedrock, to locate sub-pavement voids, and to determine the thickness of surficial chat. In the field, the dual GPR transmitter/receiver antenna is normally moved across the ground or water surface at a relatively constant rate (normal walking speed). The antenna (transmitter mode) emits pulsed, low frequency EM radiation at regular distance and/or time intervals (normally inches or fractions of seconds, respectively). Some of this downward propagating pulsed EM energy is reflected at subsurface interfaces (lithologic or material contacts), returned to the antenna (receiver mode) and recorded (arrival time, amplitude and antenna location). These reflected data are recorded as traces, processed and placed side-by-side (at appropriate spatial locations), thereby provide a relatively continuous time-profile of the subsurface. Ideally, subsurface interfaces/features of interest can be identified and correlated across the GPR profiles, and time-depths can be transformed into structural depths. The effectiveness (depth penetration/resolution) of the GPR tool is dependent on the soil/rock/material properties of the features studied and the frequency of the antenna employed. Clayey soils absorb/attenuate GPR signal and often preclude the effective imaging of underlying strata. The antenna frequency also controls penetration depth and resolution, with the lower the frequency antennas (i.e., 100 Mhz) providing for greater depth penetration (tens of feet maximum) but less vertical and horizontal resolution. The maximum antenna frequency employed in this study was 1500 MHz. A detailed overview of GPR is provided in Appendix B, "Ground Penetrating Radar for Subsurface Investigation." GPR was utilized in almost every project included as part of this comprehensive report. Two of these investigations, "Ground Penetrating Radar (GPR): A Tool for Monitoring Bridge Scour" and "Evaluation of GPR as a Tool for Determination of Granular Material Deposit Volumes" are located in Appendix C and Appendix D.

The high-resolution shallow reflection seismic technique is the most time, labor and equipment intensive method employed in this study. An in-depth description of reflection seismic is in Appendix E, "Overview of the Shallow Seismic Reflection Technique." The reflection seismic tool employs a man-made acoustic energy source and arrays of motion-sensitive receivers (geophones). The tool is somewhat analogous to the GPR tool in that the arrival times and amplitudes of pulsed reflected acoustic energy is recorded and plotted to create an "essentially" continuous time profile of the subsurface. The reflection seismic tool does not provide the vertical and horizontal resolution afforded by GPR, but does allow for imaging at depths in excess of several hundreds of feet. Additionally, seismic energy is not rapidly attenuated by clays and shales. This method shows top of bedrock, faults, and sink structures quite well. The resulting images are much easier to interpret than GPR. Two separate investigations combining the reflection seismic and GPR methods are detailed in "Ground-Penetrating Radar and Reflection Seismic Study of Karstic Damage to Highway Embankments, Hannibal, Ralls County, Missouri" and "Geophysical Site Characterization: Ground-Penetrating Radar and Reflection Seismic Study of Previously Mined (Lead/Zinc) Ground, Joplin, Missouri," provided in Appendix F and Appendix G.

The electromagnetic (EM) tools employed in this survey differ from the GPR tool in that they measure the earth's inductive response to emitted, essentially continuous (over fixed time window) high-frequency, primary EM radiation. The EM induction techniques are based on the principal that the primary magnetic fields emitted from the EM tools will induce secondary electric currents within conductive subsurface materials. The relative strength and phase of these secondary electromagnetic fields is a function of the conductivity of the subsurface. The depth of investigation is similarly a function of the source frequency employed. If multiple frequency data is acquired at pre-set locations a conductivity profile of the subsurface can be created. EM proved most useful in the investigation of underground storage tanks, which is described in Appendix H, "Non-Invasive Detection and Delineation of Underground Storage Tanks."

The electrical resistivity tool employed in this study induces electrical current flow (through surface-coupled electrodes) and measure resultant potential differences at the earth's surface. The relative amplitudes of measured potential differences are direct functions of subsurface resistivities. The depth of investigation can be varied by changing the spacing of the current electrodes. Additionally, the entire array can be shifted laterally across the surface of the area under investigation. This lateral shifting of the current and voltmeter electrodes allows the user to create a resistivity profile of the subsurface. A better explanation of electrical resistivity is found in an overview paper, “Subsurface Investigation With Electrical Resistivity,” located in Appendix I. An integrated survey using electrical resistivity, GPR, and reflection seismic methods is detailed in appendix J, “Integrated Geophysical Site Characterization.”

CONCLUSIONS

This study has demonstrated the effectiveness of geophysical methods to investigate subsurface threats to existing and planned roadways. Pre-construction knowledge of subsurface conditions will facilitate route planning, remediation efforts, and reduce short-term construction and long-term maintenance costs. MoDOT should integrate these geophysical tools into investigations where typical methods would be more costly and only provide limited information. It is believed the evaluations have been successful, but examination is needed of the cost to benefit ratio to establish a rationale for employing each method on a roadway project. Change of conditions claims during construction may be reduced or eliminated with the application of these tools.

The use of Ground Penetrating Radar (GPR) as an investigative tool reduced the time and cost of the projects as compared to the traditional methodology of investigation, extensive drilling and / or excavating. Without GPR, subsurface information would be obtained by drilling auger holes through the highway pavement, shoulders, and median. Relying only on point specific information to find subsurface features can be compared to finding a needle in the proverbial haystack. In the case of voids, the impact of the numerous boreholes required would have a dual effect on the stability of the roadway. The integrity of the pavement bridging the subsurface voids would be greatly reduced, and secondly, the holes would act as conduits of stormwater, flushing additional soil and accelerating the growth of the voids.

The most economical method for underground storage tanks and buried utilities is the GEM tool. It does not provide the “immediate” data that GPR is capable of, as files must be downloaded to a PC to display. There is more reliance on the grid for referencing anomalies, but the map it provides shows a 2-D view of the site with grid lines superimposed. This information would be adequate for drilling operations, showing tanks, utilities, and sometimes contamination plumes. A preliminary site visit to collect data will be required to generate maps for the drilling operations. An engineer and a technician should be able to survey a site in one 8-hour day.

It is important to realize that geophysics only shows “anomalies”, those features in the subsurface that have different physical properties than the surrounding material. There must be a difference of contrast for the “target” to be detectable. Many of these anomalies from different geophysical methods directly correlate with one another, helping validate their existence. Each geophysical method provides a different view of the subsurface properties, and the combination of techniques provides the most useful interpretations. It is these validated areas of highest concern that should be further investigated by drilling. An efficient drilling program eliminates the “chance” encounter of features by drilling and confirming the anomalies.

The combination of GPR and seismic methods was very successful at complementing one another to provide a complete look into the shallow subsurface. The GPR (i.e. 500 MHz) can show soil and unconsolidated material properties to several meters depth while the reflection seismic goes deeper to illustrate bedrock lithology and structure. The penetration of GPR is dependent on the conductivity of the soil, which varies considerably with geography. Reflection seismic, which shows the underlying bedrock structure, is highly reliable but only necessary when the local geology and location of sinkholes and faults is unknown. Without GPR data, a typical mitigation of voids in the subgrade would be to tear out the overlying pavement, laying base rock, and re-paving the interstate roadway at an estimated cost of $45 per square yard, not including excavation costs. The high cost, amount of time required, and the associated long-term traffic delays of this scenario make it the undesirable alternative.

Geophysical tools explore the shallow subsurface without damaging pavement and disturbing the subgrade. Their ability to locate subsurface features reduces the risk of penetrating unknown underground tanks and utility lines. Time wise, GPR and electromagnetic induction allowed MoDOT to quickly map underground storage tanks, find voids and unconsolidated materials, and assess the threat of future roadway subsidence. Underground objects can be located and outlined on the surface to prevent damage by drilling and/or excavating equipment. Also, once located, marking their location on the pavement, drilling, and pumping full of cement grout can easily mitigate voids.

RECOMMENDATIONS

Any threatening roadway stability situation involving a shallow subsurface that requires quick assessment is a candidate for the application of the technologies described in this report. However, ground penetrating radar (GPR) and reflection seismic are complex tools that require skilled technical persons to operate. Also, the initial cost of the equipment may be prohibitive to purchase. The results of these studies will be used to determine if the expenditure for equipment and its dedicated personnel is warranted. At this time it is recommended to establish qualified consultants that would be able to make their services available on short notice. Prior arrangements to expedite the mobilization and data collection should be made as well. This would be in the best interest of the traveling public, ensuring safety while minimizing disruption of traffic.

The following is a summary of the recommendations made as a result of the work presented in this report:

- Establish qualified consultants that can mobilize quickly to investigate distressed roadways or structures. Most of the time geophysics is used as a reaction to a problem where quick assessment and mitigation are necessary. Benefit: The safety of a structure or roadway will be evaluated in a timely manner with non-destructive techniques. This will be used to establish an efficient drilling program to define the problem areas.

- Preliminary bridge soundings in areas of known karstic voids, pinnacle rock, underground mines, or geologic faulting should employ geophysics before drilling. Pinnacle rock is where bedrock elevations vary more than about 15 feet in close proximity. Knowing exactly where rock elevation varies or the location of suspect voids will ensure that these features are defined during the drilling process. Benefit: Structures will be adequately designed and the number of "change of conditions" claims during construction is reduced. Foundations may be altered where voids are found, increasing the safety of the traveling public.

- Newly acquired right-of-way with unmapped or suspected underground storage tanks should be investigated with geophysics to confirm and locate their presence. Benefit: May prevent "change of conditions" claims during excavation. The discovery of an unknown storage tank can cause long project delays due to the environmental implications.

- Reevaluate geophysical techniques for monitoring bridge scour in the future. GPR worked well in shallow waters but the real need is for locating scour in deep, fast moving water environments such as the Missouri or Mississippi Rivers. Benefit: The advent of a deep-water scour monitoring system will reduce the number of dives in dangerous waters. This is especially applicable during floods, such as the flood of 1993, to assess the footings of a bridge for public safety.

GUIDE TO FIELD IMPLEMENTATION

The techniques described in this report apply mostly to geological work. The geotechnical section responsible for bridge soundings, foundation studies, slide repairs, and environmental investigations will benefit from these geophysical methods. The most cost effective approach is to employ geophysics during the preliminary geotechnical investigation of areas known for karst, mines, or underground storage tanks. Planning a geophysical survey should be done with due consideration to both the objectives and the site characteristics.

Successful use of GPR is based on knowing how and where the tool is useful and how to interpret the resultant data to provide the desired information. The most important factor is the competency of the persons responsible for planning and performing the geophysical survey and interpreting the data. The user must know where GPR will and will not be effective before a project is undertaken. Effectiveness is based on soil conductivity, site geology, and topography. A GPR survey crew is usually two people - one to drive or drag the antenna and one to operate the data collector. Generally, a grid system or location tick marks are set up to reference the GPR data during the survey. As GPR systems advance, the units become more specialized and easier to use. A non-geophysicist is perfectly capable of running equipment that has been set up by the manufacturer for a specific use.

The most important aspect of the resulting data is the ability to locate imaged features in the field. The data is not useful unless we can drill or dig out the anomalies to identify and confirm their existence. Therefore, investigation sites will require measuring and marking a reference grid on the ground. It is typical to label one axis with letters and the other with numbers. It is best to have at least two of the points professionally surveyed or to use a differential GPS (DGPS) receiver to collect position coordinates on as many of the points as possible. An accurate grid system tied to real world coordinates ensures that features imaged by geophysics can be scaled and precisely located in the field as well as shown on roadway plans. DGPS systems are relatively easy and cost effective to use for this purpose. DGPS is described in the chat volume study located in the appendix.

It should not be forgotten that the instruments only image “anomalies” and that the investigation sites typically require calibration and / or geological correlation drill holes to collaborate the data. The value of a correlation hole is priceless, as it aids interpretation and fine-tuning of measurements. We must know the true extent and size of the features imaged. Therefore, geophysics does not replace intrusive techniques, but greatly reduces their use. The use of geophysical methods can aid the creation of an efficient drill or dig program, eliminating unnecessary work and making sure that the targeted subsurface features are found in the area of investigation. Random or “blind” drilling does not increase the odds of success.